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IMPROVED METHODS OF HARVESTING GRAIN SORGHUM

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Improved Methods of Harvesting Grain Sorghum

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The different grain-sorghum varieties have been introduced into the United States from Africa and Asia at various times after the middle of the nineteenth century. Since that time, especially in the last two decades, efforts have been made better to adapt them with their many excellent characteristics to our agriculture. The great amount of hand labor used in the harvest of all crops in Africa and Asia is not a great disadvantage where wages are low and workmen abundant. There, the fact that sorghum heads must be cut by hand, one at a time, allowed to dry out, and then be flailed and winnowed laboriously offers no great problem; in those regions food to support human life is of much greater moment than means of making a man's efforts more productive.

In America, methods of culture worked out for other crops have been applied to this one with partial success in adapting it to American economic conditions. The crooked stick, man or oxen-drawn, the spade, and the hoe, with their attendant hard manual labor and low out-put, have been superseded by the horse and tractor-drawn plow, the cultivator, and the seeder. Thus modern methods of production have reduced the amount of labor in the actual growing of the grain-sorghum crop, but there still remains a great amount of hand work employed in its harvest, notwithstanding the replacement of flailing and winnowing by modern threshing.

At the same time that mechanical methods have been partially applied to the culture of these crops, plant breeders have been busy in adapting the plants themselves to American agricultural conditions. Among the many improvements has been the securing of strains whose erect habit of growth of medium height not only makes them easier to harvest by hand than the very tall growing, irregular, goose-necked plants formerly produced, but renders feasible the use of machinery for this purpose.

Since its introduction into California in 1874, grain sorghum has demonstrated its adaptability to the warmer summer temperatures of our interior valleys, where with suitable methods of culture and under favorable conditions, it may be grown either with or without irrigation.

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It is heat and drought-tolerant. After the plants are firmly established, it grows vigorously, and is much less exacting in its requirements than most other summer crops. Many weeds, troublesome in our fields of small grains, are often materially reduced for succeeding crops by planting and properly cultivating grain sorghum for a year or more.

The adaptability of this plant to the conditions in our interior valleys is reflected in the yields obtained. In many sections of the state, higher yields may undoubtedly be secured from grain sorghum than from barley. Generally the price per ton is, furthermore, greater for the grain sorghum. Under many conditions the cost of growing the grain sorghum may not be much greater than that of raising barley, but the cost of harvesting in many cases offsets the advantage in yield and the price received. The purpose of this bulletin is to present observations and experiments on methods to reduce the cost of harvest.

GROWTH OF THE SORGHUM PLANT IN RELATION TO HARVEST

The actual methods to be used and their relative efficiencies are no more important at harvest time than the condition of the crop itself—a condition that is changed, sometimes markedly, by the cultural practices used and the circumstances under which growth has taken place. After the initial delicate seedling stage has been passed, grain-sorghum plants are very vigorous growing. As long as conditions are favorable, growth continues to take place. This may, and frequently does, result in a crop containing an amount of moisture too great for easy and safe harvest. As the fall season advances natural conditions for drying become poorer and poorer; rains are more apt to occur, fogs become more prevalent and last longer during the day, and the average temperature is lower. Among the important factors influencing the amount of moisture in the crop as it approaches the harvest are date of planting, variety, abundance of moisture, thickness of stand, and fertility of the soil.

In general earlier planting results in earlier maturity; in consequence harvesting may often be completed before the poor drying conditions of late fall interfere. Too early planting may, however, cut down the yield of certain varieties in the Imperial Valley, where experiments, as yet unpublished, have shown planting of milo in July to give better yields than earlier. Variety also, is tied up with date of planting; the early-maturing varieties may be planted later in the year than the late-maturing ones. These factors are generally well

understood and appreciated. The interrelated factors of stand, moisture supply, and soil fertility, which undoubtedly have a direct influence upon the growth of the crop, its condition at harvest, and the yield secured, are more obscure.

Effect of Stand and Moisture Supply on Growth.—With favorable soil and climatic conditions, a single plant of sorghum isolated from plants of all kinds will generally stool profusely and continuously. By the time the first head has matured seed, there will be later tillers or suckers varying all the way from those just emerging from a leaf bud at the crown, or even up on the plant stalks themselves, clear through the blossom stage to those almost mature. As the plant grows, more heads will mature and more new shoots will arise to form younger stalks. Under many conditions, at least, a single plant by itself cannot use up enough soil moisture and available plant food to curtail the development of new shoots. Harvesting thin stands which have plenty of moisture generally requires some agency other than natural maturity to cause the drying out of the plants.

When the plants are made to approach each other to form a row, with the row still isolated, the number of stalks per plant will be reduced below that of the isolated plant. The later shoots will, in fact, be greatly discouraged, if the plants are well crowded in the row under dry-farming conditions. Apparently this crowding induces the rapid use of the soil moisture near the crowns, and thus leaves the available supply much farther away. Work by Conrad and Veihmeyer(5)[3] indicates that the plants use the moisture nearest the crowns first, and that as the roots extend into new, damp soil, the new soil in turn is depleted in available moisture. Because the roots tend to develop in the isolated row in all directions below the horizontal, the soil moisture is used up progressively from the crown out almost equally at equal distances. There was a noticeable use of soil moisture seven feet from the crown at all angles below the horizontal.

In a system of planting parallel rows, as in a normal field, the roots growing to the side at a few inches in depth soon meet the zone where roots from the adjacent row are absorbing moisture. Unless irrigation water is supplied, the available moisture is used up in the top layers of soil; hence all roots to secure moisture must go downward using up the soil moisture as they grow. The available soil moisture within reach of the roots may not be sufficient to meet the demands of the top growth. The plants then will go into a dormancy, the leaves curling up, dying along the edges, and finally all drying up unless water is supplied. With the application of water new

[3] Reference by superscript number in parentheses is to Literature Cited, p. 41.

growth is generally encouraged by new shoots arising from the crown and from the different nodes (joints) of the stems; in consequence, the crop is often uneven in maturing.

Because of marked variation in fertility, moisture-holding capacity, and moisture supply in the soils of this state, no given stand will suit all conditions. Some soils have the fertility and moisture-holding capacity to adequately support a very thick stand. Others, especially under dry-farming or conditions of inadequate moisture supply, are not able to support the stand that is attempted. In this state nearly every year, many hundreds of acres of grain sorghum, which have dried up at blossoming time or before, could undoubtedly have finished their normal growth and have produced a crop, if there had been fewer plants per acre.

The sorghum plant has a reputation for drought resistance, but at the time of heading and blossoming, although the plants may remain alive on a deficient moisture supply, yet a large number of blossoms may blast and not produce grain. A soil-moisture deficiency at this time is probably more injurious to the crop than at any other stage of growth. The 'firing' just at heading time with almost complete cessation of growth often results from thick stands and an inadequate moisture supply. If irrigation water is not available or is limited, a much more normal blossoming and filling of seed may be secured with a thin stand. This may be secured by having less plants in the row or perhaps better still by having a wider space between rows.

The proper adjustment of the stand to a limited moisture supply may be difficult to attain. The appearance of young shoots or suckers from the crown and joints at harvest time usually indicates an incomplete use of the moisture available to the crop. Such a condition, if general throughout the field, may show that the stand is too thin for the conditions prevalent that season. 'Firing' of plants, small heads incompletely exserted from the highest leaf sheaths, and heads but poorly covered with seeds, on the other hand, usually indicate an inadequate moisture supply. These conditions are frequently brought about by stands which are too thick.

Where an adequate water supply is at hand and properly applied, less difficulty is apparently encountered in adjusting the stand to it. A system of culture which is fairly successful in giving heavy crops of milo, often sufficiently dry to be harvested with the combine, is being used in the Delta region and other districts of California.

In these districts a thick, even stand is secured by good seedbed preparation, moderate to heavy seeding (3 to 8 or 10 pounds per acre); relatively narrow distances between rows (28 inches to 36

inches); and heavy stooling or tillering of the plants due to the fertile soil. Adequate irrigations during the early stages of growth generally keep the stand growing vigorously. Then as the plants head out and blossom, no more water is applied. By this system of culture the plants have adequate moisture at the critical blossoming period. Consequently there is a minimum of blasting of the flowers. The growth of the plants has not been delayed at any time in the early stages because of lack of moisture. The thick stand and heavy top growth at the time irrigation is stopped promote the rapid use of the soil moisture remaining and the quick, early maturity of the crop.

Hastings[7] working at San Antonio, Texas, has shown that thick seeding there promotes early and uniform maturity of the heads of milo by repressing the tillers or suckers which are undoubtedly the chief cause of irregular ripening. Though it is the ravages of the sorghum midge there which make early, uniform maturity essential, still, when it is necessary on account of short seasons the same fundamentals are applicable. Thick stands are, then, an important factor, causing early maturity of the crop in the Delta region where growing conditions would ordinarily be expected to hinder and delay the normal maturing of milo; the summers are cool, the land is subirrigated, and in most cases it is fertile. In addition, early maturity is hastened by earlier planting. Some farmers start their seeding there by April 1 but most start about April 8 to 15, finishing in general before May 1.

In other regions of the state where the combine is used for harvesting grain sorghum, these fundamental practices of the Delta region, namely, (1) early planting, (2) heavy stands, (3) copious early irrigations, and (4) no irrigation after heading, may not be so rigorously followed. A warmer and longer growing season hastens maturity so that more leeway is possible on any one of these practices. Generally, however, the only changes are the somewhat later planting that may be followed elsewhere, and in many cases a somewhat lighter rate of seeding.

Effect of Stand on Yield.—Yields as well as growth may be affected by stand and moisture supply. At Davis in 1925, four plots irrigated during the growing season and five without irrigation were harvested for each one of the treatments listed in table 1. The yield of the Double Dwarf milo was definitely increased by widening the space between rows from 3½ to 7 feet where no water was applied; the average yield for the Heileman milo grown in adjoining plots was increased, also, but not sufficiently to be considered any more than an indication. Under irrigation, on the other hand, the rows spaced 3½

feet apart slightly out-yielded the 7-foot spacing. For neither variety would these differences be considered definitely significant, though with the Heileman milo there is a strong indication in that direction. Figures 1 and 2 show typical heads of Double Dwarf milo produced by the two spacings without irrigation at Davis.

Fig. 1

Fig. 2

Fig. 1.—Heads of Double Dwarf milo blasted because too thickly planted in 3½-foot rows without irrigation. Yield of grain per acre, 875 pounds.

Fig. 2.—Normal heads of Double Dwarf milo, planted in rows 7 feet apart without irrigation. Yield of grain per acre, 2,684 pounds. See table 1, p. 8.

TABLE 1

EFFECT OF VARYING DISTANCE BETWEEN ROWS ON YIELD OF GRAIN SORGHUM, DAVIS, 1925

Treatment and variety	Number of plots in treatment	Yield per acre, pounds threshed grain			Odds, Student's method*
		Rows 7 ft. apart	Rows 3½ ft. apart	Difference	
Irrigated:					
Double Dwarf milo	4	3,012±138	3,136±200	−124±244	5.8 to 1
Heileman Dwarf milo	4	3,696±248	3,860±288	−164±380	20.3 to 1
Non-irrigated:					
Double Dwarf milo	5	2,684± 62†	875±169†	1,809±181†	735 to 1
Heileman Dwarf milo	5	3,158± 98	2,868±188	290±212	4.3 to 1

* The probable errors of the means were computed by Bessel's formula; and the odds by Student's method were secured by pairing according to the method given by Love and Brunson[10].

† Because the thinning to produce the stand desired was somewhat delayed, these yields probably favor the plots with the 7-foot spacings.

The annual rainfall diminishes in the Great Plains Region as one goes farther west. At Hays, Kansas, Cole and Hallsted[2] report for the five years, 1916 to 1920 inclusive, an annual yield of threshed grain per acre of 10.7 bushels from kafir ordinarily spaced and of 15.1 bushels from kafir spaced with twice the normal distance between rows.

Rothgeb[12] at Amarillo, Texas, still in the somewhat arid part of the Great Plains, secured with Dwarf milo and Dawn kafir yields that slightly favored the 3½-foot rows over the 7-foot ones. In dry years the 7-foot spacings markedly out-yielded the 3½-foot ones with the same number of plants per acre. In wet years the opposite was true.

Sieglinger[13] working at Woodward, Oklahoma, with the climate slightly more humid than the others, also secured the highest yields for the wide-row spacings in years unfavorable with respect to rainfall, and the highest yields for the normal-row spacings in favorable years. The general 5-year average favored the normal spacings somewhat more strongly than did that at Amarillo.

Although in a great number of cases, wider spacings may give better yields where irrigation water is not supplied and natural subirrigation does not occur, still, in certain situations soils of high water-holding capacity may produce a heavy vegetative growth and yet retain enough moisture to finish off a very heavy crop of grain. In 1928, the writers examined a large field which had been irrigated only before planting; the yield of threshed grain from six pounds of seed planted with normal spacing of rows was over 4,000 pounds per acre.

The stand may, theoretically, be too thick for best yields even though the moisture supply is adequate. When the moisture supply is inadequate, a thick stand uses up the available moisture to produce a heavy vegetative growth and leaves an insufficient amount to finish the crop. Similarly, with the moisture supply adequate, the available fertility may be used up in producing a heavy vegetative growth and not enough may remain available for the last stages of growth when the grain is filling. This is probably one of the causes of the results secured at the Imperial Valley Experiment Station under irrigation. Table 2 gives the results of the spacing tests there from 1922 to 1924. These results, though by no means conclusive, indicate that under the conditions of these tests, the space between rows from 30 inches to 90 inches has had no very great influence on the amount of threshed grain per acre. Even though moisture has been resupplied by irrigation, the available fertility has not been supplied rapidly enough to give the closer-spaced rows the higher yields.

TABLE 2

EFFECT OF VARYING DISTANCE BETWEEN ROWS ON YIELD OF HEILEMAN MILO

(The distance between plants in the rows was 6 inches in 1922, 9 inches in 1923, and 6 inches in 1924. The experiments were conducted at the Imperial Valley Experiment Station.)

Distance between rows in inches	Yields in pounds of threshed grain per acre				
	1922*	1923*	1924†	2-year average 1923–1924	3-year average
30	1,891	4,550	1,729	3,140	2,723
42	1,780	4,365	2,222	3,294	2,789
54	1,604	4,895	1,863	3,379	2,787
66	2,500	4,335	1,964	3,150	2,933
78	‡	4,150	2,260	3,205	.....
90	2,441	4,140	1,982	3,061	2,854

* Average of duplicate tests.
† Single series of tests only.
‡ This spacing was inadvertantly left out at time of planting.

In 1927, at the Imperial Valley Experiment Station, Dwarf hegari was planted in rows alternately 3½ and 7 feet apart, as well as in rows all 3½ feet apart. The yields in pounds of threshed grain per acre were as follows:

Spacings of Dwarf hegari	Yields
Rows alternately spaced 3½ feet and 7 feet	3,288
Rows spaced regularly at 3½ feet	3,078

From these observations it is apparent that variations in soil, moisture supply, and fertility may effect, sometimes markedly, the best stand which a field of grain sorghum may carry to maturity. In general, where either soil moisture supply or soil fertility is limited, higher yields of threshed grain may be secured by greater spacings between rows. Where moisture supply and soil fertility are adequate, the closer spaced rows should give the higher yields.

HAND HEADING

A number of different systems are used in harvesting grain sorghum in California. Several different factors apply in a given case to determine the best system to use in securing the most efficient harvest at the least cost. Among these are the size of the field, the variety grown, the condition of the crop (especially as related to maturity), the experience and skill of the farmer, the labor and equipment available, and the condition of the weather. Not all men using the same general system will follow the same methods in detail throughout.

In the hand-heading system the heads when mature or approaching maturity are cut from the plant with a special knife, a large pocket knife, a suitable fruit knife, or hand pruning shears. In the harvesting of small acreages, the heads may be thrown into a wagon equipped with a stop or "throw" board, or in larger fields contract labor, hired at rates per acre, which depend upon conditions, may be employed to cut the heads and put them in small piles through the field. These are then collected and hauled to a central place where, if dry, they may be thrown in a larger heap to await the thresher. If too wet, they may be put out in long windrows until thoroughly dried. They are then threshed by a stationary thresher or by a combine from which the reel has been removed to facilitate pitching on the draper. The combine may be hauled along the windrow or the heads may be hauled to the combine and men and teams used to take the straw away.

Where fields are small, this method is usually employed, because it takes the minimum amount of equipment and is adapted to all varieties grown and to most conditions of the crop where the seed has completely or nearly completely filled. The system is, however, not economical of labor. Where the heading is done by the acre, very few fields with fair to good yields are contracted at less than $5.00 an acre, and usually in addition the farmer must haul the heads from the field to the pile for threshing. In the river-bottoms of the upper Sacramento Valley some fields were contracted on the basis of $0.35 per threshed sack (about 130 lbs.) for heading, hauling, and piling White durra (White Egyptian corn or White "Gyp"), the contractor to furnish all equipment and board the men at his own expense. The outlay per acre for this work alone, in which the yields reported by farmers are often from 35 to 40 sacks an acre, would be from $12.25 to $14.00 an acre. Custom charges for stationary threshing are generally 15 cents or slightly less for a sack of 125 to 135 pounds.

One drawback to this system besides high cost is the danger of rain damage while the heads are in piles or windrows on the ground. This problem is apt to be especially troublesome when the piles are out late in the season, after the beginning of the fall rains and fogs.

MACHINE HEADING

Various machines, some especially designed, are being used to cut the heads from the grain-sorghum plants and deposit them in wagons alongside of which they are drawn or upon which the more simple ones are mounted. The one-row heading devices may be mounted upon either the side or the front of the wagon box. In the latter case

a split tongue is provided to allow the heads to come up to the cutter. Generally these machines are utilized for harvesting small areas only. With the shorter, upright varieties such as Double Dwarf milo and with similar upright-growing ones, the grain header has been used with success, the header wagons being handled in practically the same manner as for heading small grain. For the taller and more unevenly growing varieties, different manufacturers have designed special features to go on the headers in order to cut the stalks with the shortest possible stems remaining on the heads. In each case the heads are deposited in piles or windrows to dry while awaiting the thresher. With the machine heading, a greater amount of stalks and leaves generally goes into the piles and if still green makes the rate of drying correspondingly slower.

Not enough machine heading has been done in California to enable us to compute the per-acre cost very accurately. Adams[1] gives the cost of heading barley and wheat under difficult conditions as varying between $2.00 and $3.50 an acre. Heading Double Dwarf milo with a grain header might be expected to cost as much or more. The one and two-row special headers for cutting the stalks close to the head are generally equipped with an auxiliary engine and do not cut so wide a swath; hence the cost per acre would be higher. Estimates from the actual experience of farmers put the expense at from $3.50 to $7.00 an acre. The heads in piles or windrows are still subject to the same danger of rain damage as occurs in hand heading.

BINDING

The corn binder is sometimes used to harvest the medium to taller growing varieties of grain sorghum in the Great Plains regions of Kansas, Oklahoma and Texas. According to Martin, *et al*,[11] after the plants have dried out in the shocks the grain is threshed in a number of ways. A broad ax or 'cheese knife' may be used to cut off the heads, which are later delivered to the thresher. For stationary threshing a vertical sickle bar is provided on some combines to cut off the heads from the bundle in such a way that they will fall upon the 'draper.' Whole bundles may be fed into a thresher, or fed part way and then discarded as soon as the grain is threshed off.

One large operator in California has used a corn-binder without twine to deposit the Dwarf milo plants in bunches in the field. After the grain has dried, a crew of seven places these bunches on the draper of a combine, as it is pulled through the field. Later in the season,

as danger of rain and fog approaches, twine is used in the binder, and the bundles are shocked.

In the Sacramento Valley the rice binder has been used to some extent on the Double Dwarf milo and on other varieties whose height is less than usual. Figure 3 shows rice binders harvesting Double Dwarf milo by means of power take-off devices from the tractors. Very short plants cannot be bound without excessive loss.

Fig. 3.—Harvesting Double Dwarf milo with rice binders in the Sacramento Valley.

When the bundles are properly shocked, the grain is less liable to become wet by rain than are heads in close piles or windrows on the ground. After drying, the whole bundles are put through the thresher. The cost of this method of harvest on the basis of custom work with rice equipment is approximately $4.50 to $5.00 an acre for binding, $1.25 an acre for shocking (this may not be necessary) and $0.40 a bag for threshing by the regular stationary equipment and crew of wagons, loaders, and 'feeders.' Undoubtedly threshing with a properly adjusted and equipped combine pulled through the field might materially reduce the cost below that of the regular stationary method.

COMBINING

Combines (combined harvester-threshers) have been used to harvest milo in California for at least 18 years in certain parts of Kern County, and at least 12 years in the Delta region near Stockton. Many of the early attempts were only partially successful. Improvements making for an easier, safer, and more efficient harvest have been

gradually evolved. As discussed above, the cultural practices and varieties used have, on one hand, been modified to give a more uniform maturity of the crop. Changes and adjustments evolved on the harvesters themselves have, on the other hand, been made to adapt the machines to this work.

Adjustments and Alterations for the Header.—The adjustments and alterations made on the combines used are important in carrying on the work easily and efficiently. If no alterations are made, the ordinary reels may throw the heads of grain sorghum rather badly. The change usually made where special reels are not employed is to

Fig. 4.—The slats of ordinary width, as they occur on reels for small grain harvesting, catch and throw many of the heads. Widening the slats with wider boards as in the figure above, wire netting, or canvas, will almost eliminate the throwing of heads by the reel.

widen the slats of the reel with boards, wire screening, or canvas, as shown in figure 4. This should prevent the heads from hanging on the reel slats and being thrown as the reel revolves. The back of the header behind the draper is also built up to prevent the throwing over of the heads. Occasionally the height of the milo growth prevents the ordinary reel from handling the crop without considerable wastage of grain. Recently Hoefling[8] has described an extra large reel, 8 feet in diameter, which he has found to work satisfactorily on the taller-growing varieties of milo and durra (Egyptian corn).

Two other specially built reels and headers are being made and successfully used. One consists of a series of slanting hardwood arms, about 6 inches apart, bolted to each side of a square box around the reel shaft. This type, manufactured at Stockton, is coming into use

around that city. Figure 5 shows it working on a combine in a field of Dwarf milo. Apparently this type operates more easily and throws heads less than the slatted reel.

The other, a more radical change in the header itself, is typical of the alterations made on their own machines, and successfully used, by growers in the Lake Tulare region of Kings County. Each of the lower guards of the sickle is removed and replaced by a guard specially made about 2½ feet long, with sides parallel except that the last 4 to 6 inches is tapered to a point. The distance between adjacent guards is approximately 1 inch. The original guard removed is altered by

Fig. 5.—Slanting hardwood arms without slats are being increasingly used in place of the ordinary reel in the harvesting of grain sorghum.

taking off the flange, turning it upside down, and putting it on top of the sickle. These lower guards make a series of slots, each of which registers with a section of the sickle bar, the whole assembly being like a large 'stripper.' A header so equipped is shown in figure 6. In operation the stalks of the milo slip into these slots. The forward motion of the machine causes practically all of the stalk to slip through, leaving only the heads and some leaves above the guards. As the head is too large to go through the slot, the stalk is pulled into the sickle and the head cut off. A sloping board over the long guards bends over the heads and tends to shorten the parts of the stalks remaining upon them. A small reel about 18 inches in diameter, made entirely of iron or steel, revolves behind the sloping board and over the sickle to direct the cut heads on to the draper. About the only drawback so far encountered is the necessity of backing up the machine

when weeds catch on the points of the long guards. Hoefling[8] has used 2-foot wooden guards set above the regular ones with the ordinary type of reel to catch leaning and bent heads.

In order to 'get over the ground' machines must often start threshing early in the morning, when the dew or fog is on the sorghum plants. Later in the afternoon the plants may be rather dry. These variations in the moisture conditions cause contraction and expansion of the canvas draper in the header. A few machine operators find, however, that a draper if oiled, runs rather uniformly

Fig. 6.—A typical combine header for harvesting grain sorghum in the Lake Tulare region. The long steel guards and sloping board above reduce the amount of stalk cut off with the heads. (Courtesy of Mr. Wallace Sullivan, County Agent, Hanford, California.)

throughout the day. The milo stalks at best are hard on it, but apparently the damage is reduced by running the oiled draper fairly tight.

Where sub-irrigation has been excessive, the milo plants may lodge just before harvest time. Under many conditions this would necessitate harvesting by hand. Most machines in the Delta region are equipped with the so-called 'Hampton bar,' a special type of sickle, used to pick up lodged small grain. It can cut about as closely as a mower. Machines so equipped have very little trouble in getting nearly all of the lodged milo. Since the whole plant must go through the machine, however, the rate of threshing is somewhat cut down in these lodged spots.

Adjustments and Alterations for the Separator.—Adjustments and minor alterations in the separator itself are generally necessary to

increase efficiency and speed. Change of pulleys to reduce the speed of the cylinder to about three-fourths of that used for wheat while the rest of the machine is kept going at a normal rate generally reduces excessive cracking of the seeds. Though working conditions, types of machines, and the individual ideas of the operator vary, many successful threshermen, working with grain sorghum under ordinary conditions, use 1 or 2 rows of teeth in the rear concave, a 'blank' in the center and from 1 to 2 rows of teeth in the front concave. Under dry threshing conditions, as after a frost, a 'blank' may be substituted in front. The adjustment of the concave should be regulated according to the moisture conditions and the work desired. Generally a little more grain can be threshed out by setting the concaves close, but more seed is cracked. Cracked seed is considered undesirable if the grain is to be sold, but it should not prove such a detriment if the grain is to be used on the farm, provided it is dry enough for safe storage.

The heavy stalks with their high amounts of moisture cause difficulties for two reasons. On one hand they clog up the machine designed to handle the lighter straw of the small grains; on the other their high moisture content may be imparted to the drier grain, if the stalks are ground up fine enough to pass into the sack. These conditions make it desirable that the stalks be worked through the machine and out behind as rapidly as possible. Some help is given by the type of header shown in figure 6, because with this device less stalk material goes into the machine. Ordinarily increasing the 'wind' and using a non-choke screen in the shoe are material aids; but undoubtedly cutting down the work of the return elevator to the minimum is the most effective.

Some of the successful operators of machines having chaffers at the rear of the shoe completely cover these with sheet metal or with screens only a little larger in mesh than those in the shoe. If the chaffer is left as for small grain, many heavy sorghum stalks will work into the return elevator and go back to the cylinder. Here they are ground up finer so that next time they go more easily through the chaffer. This process continues until the stalks are as fine as the grain and, being approximately as heavy in their moist condition, go into the sack. This constant circulation of the fine stalk material around and around through the machine causes frequent stops for cleaning out the return elevator, and so taxes the separating capacity that there is often inadequate opportunity for the grain to go through the sieves; in consequence, a considerable amount is lost behind in the stover. The complete covering of the chaffer has, in a number of

cases, almost entirely prevented the ground up stalks from getting into the sack, has nearly eliminated stops due to clogged return elevators, and has allowed maximum output in threshing.

Certain types and spacings of straw carriers in which the slats are affixed to the links of a chain are a fertile source of trouble unless some adjustments are made. The heavy sorghum stalks working through the wide spaces between the slats, clog up the carrier and cause frequent stops. By doubling the number of slats one can practically eliminate this trouble. The space thus left is so narrow that a whole sorghum stalk cannot get in; yet little bunches of unthreshed seed may still have room to work through into the return elevator.

Throwing out the clutch while turning, or at other times when the machine is not actually taking in new material, generally keeps the shoe loaded, so that green material has much less oportunity to work through with the grain. In harvesting grain sorghum in windy regions some growers enlarge the canvas straw discharge housing to about three feet wider than the machine and extend it nearly to the ground to get the full efficiency from the fan.

Combining and the Weather.—It is a common practice in the Great Plains Region of Texas, Oklahoma, and Kansas to wait for fall frosts to kill the plants before combining. During the clear weather following the frost, the plants dry out so that the grain will ordinarily be dry enough to keep after harvest. In the Sacramento and San Joaquin valleys the early frosts cannot be depended on, and waiting for them increases the danger from early fall rains and from the dripping fogs of December and January. Frosts if they do occur early or even in the middle of the harvest season, are a material help in drying out the grain. Many growers notice that the amount of threshing done per day is greatly increased by a few days of drying weather after a frost.

One advantage of using the combine lies in the upright position of the crop in case of a storm. A rain falling upon an unharvested field will undoubtedly wet the heads somewhat, but a large amount will run off upon the ground. With drying weather following the precipitation, the standing heads, each by itself in the sunshine and breeze, will dry out more quickly than wet heads in piles on the ground or in bundles. Recent experience in Illinois,[9] where the combine is being increasingly used for small grain harvest, show that wheat standing in the field for the combine will dry out more rapidly than shocked and bound grain which has been wet by a rain.

Costs of Combining.—Apparently very little custom work is done in combining grain sorghum. Most operators feel that the charges

for custom combining of this crop should be about the same as for barley per acre, per hour, or per ton, whichever is the prevailing custom. Grain sorghum ordinarily is freer of weeds than is barley, but it is harder on the thresher. Most growers feel that the greatest disadvantage of the grain-sorghum harvest is the shorter hours worked because of the shorter days at that time of year. Ordinarily the men on the harvester have to be paid as much for the shorter day as they received in summer for the longer one. If, on the other hand, it is considered that the overhead charges of interest and of a part of the depreciation is charged to the small-grain crop harvested earlier in the year with the same combine, the overhead charges for the extra use of the machine for grain sorghum are that much less. In one case where barley had been threshed for $0.20 a sack (of about 100 pounds) custom work on milo was being done for $0.25 a sack (of about 125 pounds).

Cost figures given herein are on the basis of custom charges reported as being made. The actual costs vary from the usual custom charges, which are in general undoubtedly made somewhat higher than the actual costs to allow some profit to the operator or contractor. In 1925 studies made by Stirniman[14] on the cost of operation of 37 combines working on small grains showed an average labor cost of $1.57 an acre with a range of from $1.16 to $2.71 an acre where the grain was sacked. Maintenance costs (i.e., repairs, labor, parts, and material, ranged from $0.044 an acre to $0.198. Interest, depreciation, and replacement were not studied. Though the custom charges for combining vary with a number of factors, the general prevailing charge for harvesting in localities covered by these studies was $3.00 to $3.50 an acre.[4]

[4] More detailed cost surveys of harvesting grain sorghum have been made in the Grain Sorghum Belt of Kansas, Oklahoma, and Texas. Martin *et al*[11] give the following figures for total operating (but not overhead) expense computed on the basis of $2.75 a day for each man and $0.40 for each horse.

Method	Cost per bushel (56–58 pounds)		
	Harvesting	Threshing	Total
Hand heading	$0.100	$0.045	$0.145
Cutting with row binder	0.060	0.070	0.130
Cutting with grain header	0.035	0.065	0.100
Combining	0.033		0.033

Ellsworth and Baird[6] give the following figures for both operating and overhead costs secured in a survey in Oklahoma and Kansas. Operators used their own equipment in the cases reported below.

Method	Cost per bushel		
	Harvesting	Threshing	Total
Combining	$0.042		$0.042
Cutting with grain header	0.035	$0.017	0.052
Cutting with row binders	0.100	0.075	0.175
Hand heading	0.093	0.019	0.112

Artificial Drying.—Sacked grain coming from the machine practically free from foreign material may yet contain too much moisture for safe storage. A factor of security under such conditions is the location of commercial driers at advantageous positions. At least seven of these firms make a business of drying grain sorghum, though two dry rice mainly. The driers are distributed as follows: Guernsey (Kings County), 1; Oakland, 2; Petaluma, 1; Sacramento, 1; Stockton, 2. Each has a capacity of from 40 to 100 sacks an hour. Air heated by steam coils to 160° to 200° F is used for the drying. This heat injures the germination of the seed, hence grain so treated should not be planted.

Most men in charge of drying and storing milo consider that 14 per cent is about the highest safe moisture percentage at which grain sorghum may be stored for all season, especially if the storage conditions are somewhat damp. Where fogs are prevalent some prefer that the moisture percentage be as low as 13 per cent. Martin *et al*[11] of the United States Department of Agriculture consider 13 per cent moisture as about the highest percentage for safe keeping during warm weather.

Recently, Coleman *et al*[3] concluded from respiration and storage experiments in the laboratory that "if the temperature is sufficiently high (100° F or more) sorghum grains that contain over 14 per cent of moisture will go out of condition." Their data indicate, also, that lots having considerable quantities of cracked seed present at excessive moisture contents deteriorate more rapidly than do lots of whole seed at the same moisture content. Lots of seed which have started to heat once apparently are more liable to heat a second time, unless the moisture content is within safe limits.

Though charges for drying vary with the firm, the size of the lot, and the amount of moisture to be dried out, in general in large lots the charges are $2.50 a ton to dry out the first 5 or 6 per cent of moisture or less, and $0.25 to $0.50 a ton more for each additional per cent of moisture. These charges include at least a rough recleaning and in most cases handling charges to and from the drier, but storage in each case is additional. Thus growers with large acreages to harvest who expect to have considerable drying done, may start combining as soon as the moisture percentage is down to 19 or 20 per cent. By the time the moisture percentage reaches about 14 per cent considerable acreage will have been harvested and drying can be dispensed with until rainy weather or fogs cause the moisture percentage to go up again.

Advantage may be taken of the 'milling in transit' freight rates to reduce materially the transportation costs otherwise involved. Under this arrangement the total rate to the final destination is no greater because of the stop at the drier than that for non-stop shipment there; but the payment is generally made in two parts; the regular rate to the drier, and after the lot is dried, the additional amount when it goes forward. In planning on use of this privilege the grower should remember that the shipment must go forward and not back on itself after the drying is done.

If the grain is not too moist and the weather conditions are favorable, some measures may be taken on the farm to reduce the moisture percentage to safe limits. Where the grain contains even a small amount of moist stalk material, an immediate recleaning will prove beneficial. The grain, going over the screens and through the 'wind' will, if the air is dry, lose some of its moisture. In warm, dry weather, standing each sack by itself on end in the field, will be helpful. Martin *et al*[11] describe the dumping of moist threshed grain sorghum upon the ground in the Great Plains until dry enough to keep. One California grower reported using this method successfully in a rainless September. When the weather is rainy or foggy, none of these methods are apt to avail, because the atmosphere nearly or completely saturated ordinarily lacks the capacity to absorb more moisture unless the temperature is raised.

ROOT CUTTING AND COMBINING

At Davis and elsewhere in the state, in cooperation with growers, root cutting has been tested as a means of drying grain sorghum plants artificially before harvesting with a combine. Under many conditions in California the grain may fill normally but not be sufficiently dry for safe storage if harvested. Many farmers wish, furthermore, to use their own grain for feeding on the farm where it is raised. The cost of transportation involved in artificial drying might be almost prohibitive under such conditions. Under other circumstances where the yield of top growth is not too heavy to interfere seriously with the mechanics of root cutting, this system may prove more economical.

Planting to Facilitate Root Cutting.—Many ways of planting have been tried for the root-cutting tests; others suggest themselves. Where tractive power is available with enough clearance to pass over the heads of the Double Dwarf varieties (from 20 to 26 inches high), a field may be planted solid and handled with the ordinary planter and cultivator,

and a suitable cutter used at time of harvest. The rows should be spaced to give adequate clearance between the plants and the wheels of the tractor (i.e., 8 to 10 inches) or suitable guards should be provided at the time of root cutting to prevent heads from being pulled to the ground by the rotation of the wheels. Where a one-row cutter can be used with horses, any normal spacing may be used.

With the larger-growing varieties which attain a height of from 4 to 6 feet, it is improbable that the tractive power available would be high enough to clear the tops of the plants. In root-cutting these varieties the base of the plants is perhaps best reached if every other space between rows is widened, so that a tractor may easily go through. With the upright-growing varieties and the smaller tractors, a 6-foot spacing may be the minimum required. At least 9 inches on each side of the center of the row should be allowed for space to manipulate the tractor and for tillers to spread out in the row. Several tractors now available on the market will give adequate clearance when used between rows planted 6 feet apart. For this type of cutting, the planting, if very accurately done, can be accomplished with the ordinary 2-row planter by simply lengthening the marker bar the necessary distance; i.e., if the rows are to be 3½ feet and 6½ feet apart, respectively, the bar should be long enough to make a mark exactly 10 feet from the center of the planter. The greater side draft of the longer bar causes some difficulty until the teamster makes the proper allowance in driving. In the cultivation of the crop, the total space should be kept free of weeds.

Planting that will register better with the root cutter can be done by extending the 2-row planter as shown in figure 7 to the desired width for the wider space. In the case taken above the shoes should be 6½ feet apart.

Some of the farmers in the Sacramento Valley provided for planting by using 4-row beet drills with the two center standards removed. Milo plates for dropping the seed were provided. Cultivation is most easily accomplished by making provision for the cultivator to follow the same rows as have been planted together.

Where multiple-row planting is to be followed in large fields, a suitable assembly of machines can be made up of a group of unchanged 2-row planters in the center and on either side a 1-row planter. Thus for planting 6 rows at one time the machines would be in order from left to right; a 1-row planter, a 2-row planter, a 2-row planter, and then a 1-row planter. The desired distance for root cutting should be maintained between adjacent planters.

Root-cutting Equipment.—In the root-cutting experiments at Davis, two general types of blades were used. One, at right angles to the line of draft, was supported on either side by an upright, making a U-shaped attachment for sled or cultivator, as shown in

Fig. 7.—Seeding alternately wide and narrow spaced rows with a planter extended to 7 feet. This method greatly facilitates root cutting, for the cutter registers accurately with the two rows planted together.

Fig. 8.—The U-shaped blade attached to a sled cutting Double Dwarf milo. The last plant root-cut has been tipped over to show the blade and the sod.

figure 8. This blade worked most successfully when so inclined as to give a suction of about 1 inch in 4. The front parts of the uprights should be sharpened and they should be closer together at the front than at the rear in order that clods cut off will not become wedged,

but have clearance until past the blade. This type was prone to clog in weedy ground or on the sorghum plants themselves, when the blade did not register with the row. Figure 10 shows two of these blades on a cart prepared to root-cut a field of Double Dwarf milo.

The other blade was a sloping one fastened at the end and inclined at a 45° angle with the line of draft, the other end being unsupported. In actual cutting, two blades of this type are necessary, one right-handed and one left-handed to equalize or balance the side-draft in cutting. Each blade was approximately 27 inches long, giving a cutting width of about 18 inches. The horizontal part of the blade shown in

Fig. 9.—A cutter equipped with a U-shaped blade operating in a field near Winters, California.

figure 12 was tipped down at an angle of 15° (or a slope of about 1 inch to 4 inches in width of blade). The fin on the outer end was put on to cut any side roots which would otherwise keep the plants green by supplying moisture from the deep layers of soil. The sloping blade will ordinarily clog very little if given a 45° angle; it is in this respect much superior to the straight blade. Under weedy conditions in loose soil, however, it will clog somewhat. A cutting coulter mounted in front of the shank of the blade materially remedies this difficulty.

Sloping blades made of $\frac{5}{16}$-inch by 4-inch plow steel as described above were strong enough to withstand a drawbar pull of 750 to 900 pounds per blade or a total pull of 1,500 to 1,800 pounds for both blades. In tests where drier, heavier soils were encountered, these blades were bent out of shape when the drawbar pull for each blade

went up to 1,300 pounds. For heavier work, thicker blades were constructed. To economize on material, a piece of plow steel 3/8 inch x 14 inches x 40 inches was cut diagonally and then the bends were made. .This gave considerable width where the horizontal part of the blade fitted on to the vertical and less width near the end of the blade. These blades withstood a total drawbar pull of 3,000 pounds witnout bending and would undoubtedly have withstood much more.

The blades were tried on a number of different carriages and sleds. The U-shaped blade was adapted to a 1-row riding cultivator which was satisfactory in cutting a single row in soft or mellow ground. This carriage did not, however, have sufficient weight or strength for cutting on hard, dry ground.

In the initial experiments at Davis[4] in 1925, the sloping blades were fastened to standards on either side of a 6-foot tractor cultivator. The cultivator was provided with a traction lift to pull out the blades at the ends of the rows. Considerable difficulty was experienced in keeping the blades in the ground to an equal depth. Increasing the suction and giving the blade a slight bow down in the center so that the greatest depth was maintained directly under the crowns of the plant, resulted in a fairly satisfactory cut. The two-wheel cultivator with sweeps placed on the sides was very difficult to pull accurately through the rows because of unequal draft on the blades. This difficulty was overcome by having a man ride on the cutter to shift about, thereby counteracting the action of the difference in blade draft. Several farmers avoided the difficulty by using cultivators with wheels farther apart.

In the experiments at Davis, much greater accuracy of cutting was secured by attaching the two sloping blades as shown in figure 12 on the outside of the runners (6 in. x 4 in. x 8 ft. timbers) of a heavy sled, which was chained to a tractor cultivator equipped with a traction lift in such a way that the blades could be pulled out of the ground at the ends of the rows. Adjustments were also made so that manipulation of the levers could throw practically all of the weight of the cultivator upon the sled. The runners, working down in the mulch, prevented any but the slightest tendency of the sled to twist sideways when the pull might not be exactly equal on each blade.

The kind and size of the power unit for root cutting is determined by the height of the crop, and spacing of rows, and the draft requirement. Teams can be used most conveniently in close spacing and with tall varieties of grain sorghum. Figure 9 shows the root cutting of Double Dwarf milo by a single-row, team-drawn, U-shaped cutter. The horses may be hitched in tandem, in teams of 2, 4, and 6, accord-

ing to the draft requirements. The row-crop type of tractor with a clearance of approximately 26 inches was found convenient for cutting two rows of the Double Dwarf varieties 40 inches apart, where the draft requirement exceeds that of a two or four-horse team. The equipment for cutting under these conditions is shown in figure 10,

Fig. 10.—Two U-shaped blades on a wheeled cart for root cutting Double Dwarf varieties normally spaced.

Fig. 11.—A view of the same equipment as in figure 10, showing the adequate crop clearance when the apparatus is used in fields with rows 40 inches apart.

and the crop clearance in figure 11. In the latter case, the center wheel of the tractor goes between the two rows planted together, with the two driving wheels on the outside of them. The frame has adequate clearance for varieties up to 26 inches in height, but those slightly higher might also be root cut with this equipment by the

Fig. 12.—A sled carrying two slanting blades for root cutting. The depth of cut is regulated by the orchard cultivator chassis, which also controls the raising of the blades at the ends of the rows. Experiments were carried on only with the wide (7 foot) spacings between rows. The slanting blades could be used with appropriate equipment with rows 40 inches apart where Double Dwarf varieties are grown and tractors available that would clear the crop.

Fig. 13.—The clearance between tractor and crop during root cutting of tall-growing varieties with equipment shown in figure 12.

arrangement of suitable guards, as plants of many varieties will right themselves after having been bent over. For the larger power units the 3½ and 7-foot spacing is desirable for either short or tall varieties. As shown in figure 13, the 7-foot space affords ample room for the tractor to travel, cutting the row on either side. When, because of rank growth, the heavy heads have bent the stalks down into the wide rows, some growers have found it desirable to put a guard on the front of the tractor to prevent the wheels or tracks from breaking down the bending stalks as cutting takes place.

Draft Requirements for Root Cutting.—The draft requirements for the different blades and supporting equipment used in tests at Davis are given in table 3. Apparently increasing the depth of cut increased the drawbar pull, though because of the variable soil-moisture conditions, this is not shown by the tests on September 15. The rains on October 1 and 2, by increasing soil moisture near the surface, apparently decreased the drawbar pull.

TABLE 3

ROOT-CUTTING TESTS ON YOLO LOAM AT DAVIS, 1926

Date	Rows cut at a time	Culture	Equipment	Depth	Average drawbar pull	Remarks
Sept. 3	2	Furrow-irrigated	Orchard cultivator with 2 sloping blades	Inches 8	Pounds 2,350	2 men rode cutter
Sept. 3	1	Furrow-irrigated	Sled runners with straight U-shape blade	7½	900	2 men riding
				7	750	1 man riding
				7	500	Loose ground, 1 man riding
Sept. 15	1	Furrow-irrigated	Sled runners with straight U-shape blade	6½	800	Cutting in plow sole, 2 men riding
				5½	600	Well cultivated, 1 man riding
				5½	500	1 man riding
Sept. 17	1	Dry-farmed	Sled runners with straight U-shape blade	5½	465	1 man riding
Oct. 7*	2	Furrow-irrigated	Cart with 2 straight U blades	7	900	Depth controlled by levers
				7½	950	Depth controlled by levers
Oct. 16*	2	Dry-farmed	Sloping blades on sled	7	1,750	Cultivator used for weight
				6	1,250	No weight

* Rain occurred on the following days: Oct. 1, 0.52 in.; Oct. 2, 0.75 in.; and Oct. 10, 0.74 in.

Soil Conditions and Root Cutting.—The root-cutting experiments were conducted in 1926 on Yolo loam type of soil at Davis. The results are reported in table 3. The tests at Davis in 1927 were con-

ducted on Yolo silt loam where the crop was grown without irrigation. Here the average drawbar pull was 2,600 pounds for the sled equipped with the two sloping blades. The pull varied from 2,200 to 3,000 pounds.

During 1927 a number of farmers used the root-cutting method in connection with their harvesting operation. Readings of the draft (drawbar pull) were secured on as many of these as possible. The conditions under which they were conducted, together with the readings made, are given in table 4. These show a range in drawbar pull from 350 pounds for a U-shaped straight blade cutting one row with a horse-drawn cultivator for a friable, fine sandy loam, to 4,500 pounds for sloping blades cutting two rows on rather compact clay loam. A demonstration of root cutting was made on the heavy clay loam of the Imperial Valley Experiment Station in November, 1927. The plants had been grown in ridges, which were slightly moistened from a rain a few days previous. Though no dynamometer was available, computations from the size of the tractor used indicated that the drawbar pull could not have been more than 2,000 pounds for the two rows cut at a time.

TABLE 4

Root-Cutting Tests in Cooperation with Farmers, 1927

Location	Soil type	Culture	Equipment	Rows cut	Depth *inches*	Average drawbar pull *pounds*	Remarks
Clarksburg	Sacramento clay loam	Sub-irrigated	Heavy sloping blades on sled	2	6 7–8	1,700 4,500	Crop light Crop heavy
Knights Landing	Columbia silt loam	Sub-irrigated	Uni-tiller with sloping blades	2	5–7	900 1,200	Lighter soil near river Heavier soil away from river
Red Bluff	Columbia fine sandy loam	Dry-farmed	Sloping blades on tractor cultivator	2	4–5 6 7	1,000 1,100 1,300	
Wheatland	Columbia fine sandy loam	Sub-irrigated	Corn cultivator with U-shaped blade	1	4–6	350	2 heavy horses used

Depth of Cut and Upright Position of the Plants.—If the blade cuts deep enough the plant quivers slightly, tips forward, then as the blade goes beneath the crown, tips in the opposite direction, and again settles into place as if nothing had happened. A plant with its roots sufficiently cut may be easily lifted up an inch or more, and on being released will settle into place again. A plant not cut cannot be lifted

in this manner but must be practically pulled from the ground by breaking the roots.

Plants not cut deep enough will generally topple over as they tip away from the blade. The roots of the sorghum plant are intensively developed in the soil near the crown. When cutting takes place in dry soil these roots are a very important agency in holding the soil

Fig. 14.—A group of Double Dwarf milo plants lifted from the row where root cut and set upon the field roadway. Though some of the original soil that helped to hold them in place in the row had fallen away, sufficient anchorage remained to hold these plants upright in a strong wind.

together to form a sod which, if the cut is deep enough, is the anchorage that keeps the plant in an upright position. The roots of the sorghum plant near the crown point downward in all directions inside of a cone of about 45° angle, but below the mulch they extend at all angles below the horizontal. Cutting below the mulch is, therefore, necessary in order to secure enough of the sod to hold the plant

upright. A sod of soil a foot wide, a foot long, and 6 inches deep should weigh, in most soils, approximately forty pounds, which should, under most conditions, prove ample to hold the plant upright against any force not strong enough to bend or break the stalks themselves. Figure 14 shows a group of plants lifted from the row where they were root-cut, and set upon the field roadway.

Fig. 15.—Root cutting Double Dwarf milo. Cutting blade uncovered at a depth of 7 inches.

In these tests, especially in the first year, many plants were overturned; but in no case was the sod overturned where the cut was 5 inches or more from the surface. No plants were standing where the cut was less than 2½ inches below the surface (i.e., at about the depth of the mulch) except a few which, happening to have an extra amount of space, had developed a very broad crown with many tillers. These were sometimes in such balance as to remain upright.

Evidently the type of soil has some relation to the depth at which cutting must be done in order that the plants remain upright. Where plants were cut but 5 inches deep on dry, fine sandy loam, the soil had a tendency to fall away from the roots, and some plants tipped over. Many more tipped over in that part of the field where the cutting had been but 4 inches deep. When the depth of cutting was increased to 7 inches, no tipping over of the sod was found. With lighter soil than fine sandy loam, still deeper cutting might perhaps be necessary. Figure 15 shows the sloping blade uncovered at approximately 7 inches in depth.

Reaction of Varieties to Root Cutting.—Most of the tests were made with three strains of milo: the Heileman milo, a high-yielding strain of Dwarf Yellow milo; the Fargo Straight-neck milo, a strain quite commonly grown in Ellis County, Oklahoma, and believed by Sieglinger[5] to be a cross between Dwarf Yellow milo and some white-seeded kafir; and Double Dwarf milo, a strain with fairly erect heads, which attains a height of between 20 and 36 inches. The first and third were grown in approximately acre blocks in 1925; the second and third occupied about three acres each in 1926, and were in small plots in 1927. Two days after the roots of the Heileman strain were cut, most of the plants of this variety had wilted flat upon the ground, as shown in figure 16, by the bending of the stalks just at or a little above the surface of the ground. This happened no matter whether the plants had been grown with or without irrigation. The Double Dwarf variety, when grown with irrigation, showed some tendency to wilt down after root cutting, but not more than 20 per cent of the heads were upon the ground from this cause ten days after cutting in 1925, and much less than 20 per cent in 1926. No wilting to the ground after root cutting was observed with this variety when it had been grown without irrigation, though the heads sagged somewhat. During the 1926 harvest, when there was a considerable amount of rain, stalks of the Double Dwarf variety whose roots had been cut six weeks before, showed some tendency to weaken at the joints or nodes and to allow the stalks to break and the heads to hang straight down along the sides of the stalks.

The Fargo Straight-neck milo, which in a limited test in 1925 stood up well after root cutting, was used in 1926 in a large block and demonstrated its ability to stand upright with no appreciable wilting after the roots were cut, either on irrigated or non-irrigated land. This variety is shown in figure 18, ten days after root cutting. Its

[5] J. B. Sieglinger, in private correspondence with the authors.

ability to stand upright after being root cut was abundantly demonstrated in 1927, also.

Ten days after the roots had been cut in the fall of 1925, Dwarf Spur feterita had wilted over slightly less than 15 per cent and White durra (White Egyptian corn) slightly less than 30 per cent where these varieties were grown without irrigation.

Limited trials during the fall of 1925 on 4 plants of each of 18 varieties showed that the following stood up well for six weeks through 2.43 inches of rain, and 32 days of moderate to hard north winds after

Fig. 16.—Heileman Dwarf milo 5 days after being root cut. The plant standing on the left background was missed in cutting. The choice of proper varieties is necessary for successful harvest by root cutting.

the roots had been severed; Fargo Straight-neck milo (C. I.[6] 809), Pink kafir (C. I. 432), Red kafir (C. I. 34), Black hull kafir (C. I. 72), Spur feterita (C. I. 623) and Darso (C. I. 615). The other 12 showed from 25 to 100 per cent wilting over.

Some root-cutting trials with the Dwarf milo were made by farmers in 1927. Considerable wilting over of these plants invariably occurred. The Double Dwarf milo, on the other hand, wilted but little, except where the plants, because of vacant places in the stand, had developed large heads and were not so mature as the rest of the field.

[6] These numbers refer to the Cereal Investigations numbers of the United States Dept. of Agriculture. Thanks is due to Mr. John B. Sieglinger of the Department for kindly furnishing seed of these varieties.

In trials with hegari in Imperial Valley in 1927 plants of this variety showed ability to stand up after root cutting at least until harvested about two weeks later.

Drying of the Plant after Root Cutting.—With all of the roots of each plant cut on a bright sunshiny day, the leaves gave unmistakable evidence of wilting within two hours. The following day the plants looked as if they had been hit with a heavy frost. A pronounced grayish cast to the former green color could readily be noticed at a considerable distance. In three or four days of such drying weather the plants were apparently dry enough to thresh though harvesting was deferred until somewhat later. In the 1925 season a comparison was made between the rates of drying of the grain of White Yolo and Double Dwarf milo when harvested in three different ways. In one case the roots were cut as described above; in another the stalks were cut and bound and allowed to dry in the bundle; in the other the heads were cut off and piled on the ground. At intervals samples were taken, the grain threshed, and the moisture percentages on the air-dry basis secured by drying the samples in an electric oven at 60° C a few days; all were allowed to come into equilibrium with the moisture in the air of the laboratory a month before weighing. Table 5 gives the results of these tests.

No significant differences are here apparent between the rates of drying. The dryness of the ground undoubtedly was a factor in drying out the grain next to it. A much different result would have been expected had the ground been wet or even moist from a rain or an irrigation.

TABLE 5

RATE OF DRYING OF GRAIN SORGHUMS VARIOUSLY HARVESTED AT DAVIS, 1925

Variety and method of harvest	Date of harvest	Percentage of moisture on an air-dry basis			
		Before harvest	Sept. 28	Sept. 30	Oct. 5
White Yolo:					
Root cut	Sept. 27	45.0	.....	17.0	8.9
Heads cut and piled	Sept. 27	45.0	.....	13.1	7.2
Bound	Sept. 27	45.0	.....	16.0	8.8
Double Dwarf milo:					
Root cut	Sept. 25	8.8	4.6	.....	4.7
Heads cut and piled	Sept. 25	8.8	10.4	.....	4.0
Bound	Sept. 25	8.8	11.8	.....	4.3

Drying in 1926 was slower than in the preceding season because of the greater amount of cloudy weather and rain during the harvest season. At the time of root cutting, October 16, 1926, the Fargo

Straight-neck milo had practically all seed mature but the plants were still green. Rain to the amount of 2.01 inches had fallen, wetting the ground to a depth of from 6 to 8 inches. Because of rush of other work, threshing was done with the combine on October 26 just 10 days after cutting. Several adjustments were made to reduce the amount of stalk and leaves going into the sack. Whenever a considerable amount of the leaf and especially stalk went into the sack, heating and molding of the grain followed. When only a very small amount of stalk was allowed to go into the bag, the grain kept satisfactorily. Two samples from the latter test showed 13.5 per cent and 14.0 per cent moisture on oven-dry basis at 100° C. The rest of these samples kept for months in air-tight cans without any deterioration. This represents the most severe conditions met with in the 1926 season, which was much more severe than the ordinary one.

In 1925 plants recently irrigated, where all of the roots were cut 6 to 8 inches below the surface, dried out practically as fast as did others not irrigated. In one plot, irrigated half an hour after the roots had been cut on a cool, cloudy day, about 40 per cent of the plants did not wilt. In all other cases where roots were cut off completely at 9 inches or less the plants dried out rapidly. Where the roots were not cut off completely, the plants remained alive and showed practically no effect from the cutting.

In 1926 plants were root cut and allowed to dry for several weeks until they were apparently dead. The fall rains, moistening the soil to seven or eight inches, again induced shoot growth from the crown but the leaves and stalks, which were completely dried out, did not again become green. This young growth offered no obstacle to threshing because it did not come up high enough to be caught by the sickle bar in harvesting. This fact demonstrates, however, the remarkable vitality of the sorghum plant.

Costs of Root Cutting.—With implements ordinarily found on a farm, the cost of extra equipment, labor, and adjustments should not run over $20.00 to $25.00 for each cutter constructed. Some farmers were able to equip themselves for less than $12.50 per cutter. Not enough experience has been gained to compute the expenses of general wear and tear incidental to cutting. From standard custom rates for tractors and horses, the rate for medium to large fields where the equipment is adjusted to the work and no rocks, stumps, or tree roots are encountered, should range from $0.75 to $1.50 an acre.

Combining after Root Cutting.—Root cutting before combining does not remove the desirability of making the adjustments and alterations given (p. 16) for combining direct. This applies even to

the screening or entire covering of the chaffer area behind the shoe. Because the leaves and seed apparently dry out after root cutting more quickly than do the stalks, harvesting may safely follow sooner where these are made.

Harvesting tests after root cutting were conducted in 1925 and 1926 at Davis. A small 9-foot combine equipped with an auxiliary motor was used in the work. As no alterations to the header were made, some loss resulted from throwing of heads by the reel. The chaffer area was covered, the speed of the cylinder was reduced from

Fig. 17.—Collecting the threshed straw or stover behind the combine to determine the loss in threshing.

1,000 r.p.m. to 780 r.p.m., and the 'wind' was increased to the maximum except as noted below. Traveling at a uniform speed and throwing out the harvester clutch while turning at corners or stopping gave uniform feeding. The amount of stalk material getting into the sack and the amount of cracked seed were reduced by these adjustments.

Preliminary tests with Double Dwarf milo were made to find the threshing efficiency of the machine itself. For several measured areas, each approximately one-twentieth acre in size, the threshed grain was weighed, the straw behind the thresher caught in a canvas as shown in figure 17 and the straw re-worked carefully by hand in order to screen and pick out all threshed and unthreshed grain which had 'gone over.' The grain so caught varied between 0.2 and 0.3 per cent of the grain threshed and in the sack. On two areas of the same variety,

the harvester as equipped and adjusted was tested as to efficiency in gathering the milo heads. The results are given below:

	Test 1	Test 2
Heads not cut off	7	9
Heads cut but thrown free by the reel	22	21
Total heads lost	29	30
Percentage heads lost	4.0	3.9

With proper adjustments and alterations these losses might be materially reduced.

More complete harvesting data were secured with the Fargo Straight-neck milo which had been root-cut on October 16, 1926. The harvesting of this variety is shown in figures 18 and 19. The rows were spaced 3½ and 7 feet apart alternately. Table 6 gives the results of these tests.

TABLE 6

Harvester Tests of Fargo Straight-Neck Milo

(This field was root-cut October 16, 1926, and harvesting tests made October 26, 1926.)

	Test 1	Test 2
Number of rows harvested	2	2
Length of row harvested, feet	240	210
Yield of threshed grain per acre, lbs.	2,250	2,060
Dockage in grain, per cent	1.5	2.9
Wind adjustment	Open max.	Open ½
Cracked grain in sack, per cent	5.25	5.45
Cracked grain in screenings, per cent	0.30	0.30
Moisture, per cent	13.5	14.0
Grain in threshed straw (thresher loss), per cent	0.35	0.37
Heads left in field:*		
Heads not cut, per cent	0.5	1.3
Heads cut but not threshed, per cent†	1.1	1.8

* Since the two rows root-cut at the same time did not register with the rows as planted there was a loss due to the root-cutting of 0.9 and 4.0 per cent respectively. The use of an extended planter reduces loss from this cause to neglible amounts.

† Loss from this cause is being materially reduced in practice by the alterations in the header given on p. 14.

The figures in table 6 show that cutting down the 'wind' put more stalk material (dockage) in the sack and did not decrease the amount of 'grain going over' (grain in threshed straw). Some of the losses given at the bottom of table 6 have been materially reduced where the headers have been altered and adjusted to the milo crop. If allowance is made for this possible reduction, the efficiency of the combine for harvesting grain sorghum after it has been root-cut may be easily appreciated.

Fig. 18.—The Fargo Straight-neck milo being harvested with the combine. This milo is still standing upright after having been root cut several days before.

Fig. 19.—Rear view of a combine working on Fargo Straight-neck milo which had been root cut. This variety has proven well adapted to harvesting with a combine.

SUMMARY

Grain sorghum introduced from Asia and Africa is produced almost entirely by hand methods there. Improvement of varieties by breeding and advancement in machinery methods are making it possible to produce it almost wholly without hand labor in the United States. The high cost of harvest by hand methods undoubtedly prevents wider planting of this crop, which is well adapted to the interior valleys of California.

A high moisture percentage in stalk, leaves, and sometimes seed, is the principal cause of difficulties in harvesting grain sorghum. Thin stands and abundant soil moisture aggravate this trouble; thick stands and inadequate moisture often 'burn up' and produce very little grain. Adjusting the stand to the moisture supply and to the fertility of the soil is necessary for best yields, and for uniform maturity of the plants. Thick stands, early planting, adequate irrigation during the early stages of growth, and no irrigation after the heads appear give good yields on fertile soil in many situations in California.

Hand heading and combining are the principal systems of harvesting grain sorghums used in California; machine heading and binding are used to some extent. High labor costs and risk of rain damage when heads are piled in the field are the disadvantages of hand heading; the small amount of equipment required offsets these where small fields are to be harvested. This system is adapted to nearly all conditions and varieties of the crop. Heading by machinery is cheaper than by hand in large fields, but the risk of rain damage is as high. Binding, but little practiced in California, is expensive in total cost, but the risk from rain damage is less.

Combining grain sorghum is increasing because the work can be easily and cheaply done with proper adjustments and under favorable conditions. The header of the combine must, ordinarily, be altered to prevent the loss of many heads. One of three different changes is generally used: the reel slats are widened or covered with wire mesh or canvas almost to the center to prevent throwing of heads, and the wire netting behind the draper is extended upward; a special reel of hardwood arms extending diagonally from the center replaces the ordinary reel; or special long sickle guards are provided in order to prevent much more than the heads reaching the draper.

Adjustments and alterations in the separator are necessary for efficient work. Slowing down the cylinder speed generally reduces

excessive cracking. Non-choke screens and strong 'wind' help to prevent clogging of sieves. Clogging of return elevator and straw carrier with heavy stalks, and the working of ground-up green stems into the sack with the grain are undoubtedly the most fertile sources of trouble in combining. These difficulties caused by allowing too much material to get into the return elevator are largely obviated by covering the chaffer area behind the shoe with sheet metal or wire mesh on some machines, and by doubling the number of slats in the straw carrier on others.

Plants dried out by a killing frost are, generally, combined with greater ease. The grain of standing plants awaiting the combine are less damaged by rain than that in piles on the ground.

Moist (i.e., above 14 per cent moisture) combined sorghum grain is often reduced to safe limits in commercial driers, conveniently located in central California. Recleaning and standing the sacks on end may, *if the air is dry enough,* somewhat reduce the moisture in the grain. Fourteen per cent is the limit of moisture for safe storage during warm weather.

Root cutting at from 5 to 7 inches below the surface of the soil to sever the plant from the moisture supply causes rapid drying of the grain, stalks, and leaves in dry fall weather, so that combining may often safely follow in about 10 days. Special attention to varieties and to spacing of rows is necessary. Where taller varieties and the usual types of tractors are used, alternate wide and narrow spacing of rows is usually essential. With the Double Dwarf varieties and a row-crop tractor, normal spacing of rows proves satisfactory. The drawbar pull for cutting varies with different soil conditions from 350 to 2,250 pounds for a single row of sorghum. The operating cost of root cutting, where the soil is free from obstructions, and the crop adequately spaced, should range from $0.75 to $1.50 an acre.

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